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The production and exchange of moulded-carved ceramics and the 'Maya Collapse'

Carmen Ting [a, *], Marcos Martinón-Torres [b], Elizabeth Graham [b], Christophe Helmke [c]

[a] UCL Qatar, PO Box 25256, 2nd Floor Georgetown Building, Hamad bin Khalifa University, Doha, Qatar
[b] Institute of Archaeology, UCL, 31–34 Gordon Square, London WC1H 0PY, UK
[c] Department of Cross-Cultural and Regional Studies, University of Copenhagen, Karen Blixens Vej 4, 2300 København S, Denmark

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ABSTRACT

This paper examines the production and exchange of a particular type of ceramic vase designated 'Ahk'utu' moulded-carved', by using thin-section petrography, INAA, and SEM-EDS. These vases were produced and circulated in the eastern Maya lowlands during a transitional period known as 'Terminal Classic', ca. A.D. 800–950. Significant changes, generally referred to as the Classic Maya Collapse, occurred in the socio-political order in the Maya lowlands at this time, although the pace and events leading to such changes remain poorly understood. By studying a selection of 62 Ahk'utu' moulded-carved vases from various sites across Belize, we seek to offer a new perspective on the nature of this important transitional period. Our findings reveal that two main ceramic traditions – one employing calcite and the other volcanic ash temper – are represented by the vases. These traditions guided the selection of raw materials, surface finish, and firing methods. Vases of the calcite tradition were mostly used at or around the sites where they were produced, whereas those of the volcanic ash tradition appear to have been circulated over a wider region. The co-existence of multiple production groups and distribution spheres of the Ahk'utu' vases, along with their style and decoration, is interpreted as indicating a proliferation of an ascending social segment and greater flexibility and fluidity in how the social hierarchy and political structure were maintained in the eastern Maya lowlands from the 9th century and onwards.

1. Introduction

Ahk'utu' moulded-carved vases are a major component of the moulded-carved ceramic tradition dating to ca. A.D. 800–950 in the Maya lowlands (Helmke and Reents-Budet, 2008; see also Adams, 1973: Fig. 16; Aimers, 2004: 80; Rands, 1973: Fig. 28; Sabloff, 1973; Smith, 1958). During this period, referred to by some scholars as the 'Maya Collapse' or the 'Terminal Classic', the socio-political structure of the Maya lowlands witnessed drastic changes (e.g. Aimers, 2007a; Culbert, 1973; Demarest et al., 2004; Sabloff and Willey, 1967). Even though many aspects of this process remain unknown, it seems clear that the elite and hereditary nobility were deeply affected by the changes, as reflected in the decline of Classic Maya kingship and its associated material manifestations (Demarest, 1997, 2006; Freidel, 1992; Santley et al., 1986; Willey, 1986). Among the significant changes in material manifestations were the gradual disappearance of polychrome ceramic tradition and the subsequent emergence of the moulded-carved tradition, including the Ahk'utu' vases. There is evidence that Ahk'utu' vases were produced and consumed by a newly affluent and ascending social stratum that was grappling to seize control in the ebbing of power of the royal households (Helmke, 2001; Reents-Budet and Bishop, 2015). Despite previous work that largely focused on the epigraphic and iconographic aspects of these vessels (Helmke and Reents-Budet, 2008), little is known with regards the production and exchange of the Ahk'utu' vases. Thus, the present investigation of the Ahk'utu' vases employed a combination of archaeometric methods to offer a new perspective on the nature and development of the transformations in Maya society from the 9th century onwards. The aims of the study were to: (1) examine the compositional variability of the Ahk'utu' assemblages within and between sites; (2) determine the potential provenances

* Corresponding author.
E-mail addresses: k.ting@ucl.ac.uk (C. Ting), m.martinon-torres@ucl.ac.uk (M. Martinón-Torres), e.graham@ucl.ac.uk (E. Graham), cgbh@hum.ku.dk (C. Helmke).

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of the vases; (3) reconstruct the manufacturing processes; (4) characterise the craft organisation; and (5) delineate the exchange patterns.

2. Background

2.1. Characteristics of the Ahk'utu' vases

The designation of Ahk'utu' moulded-carved was established by Helmke and Reents-Budet (2008; see also Helmke et al., 1998). They proposed that the designation covers the vessels as a 'type' in the type-variety system of classification (Gifford, 1976). Nevertheless, the label cross-cuts paste groups and as such only partly fits into the systematics of the type-variety system (Aimers, 2007b). Nevertheless, we continue to use the designation as a useful identifier for an important and distinctive group of moulded-carved vases because the label is an emic one, recorded in the glyphic texts that accompany these vases.

The Ahk'utu' vases are recognisable for their barrel-shaped vessel form, supported by three hollow oven-shaped supports, each with a circular perforation and containing a ceramic pellet (Helmke and Reents-Budet, 2008: 38–41) (Fig. 1). The exterior surface of the vases is covered with orange-red slip, and decorated with two elaborate iconographic scenes, accompanied by glyphic captions; a main glyphic text adorns the rim above the scenes. As such these moulded-carved vases can be said to emulate the decorative themes of the Late Classic polychrome vases (Reents-Budet, 1998), but these two types of vessels vary in terms of production technique and mode of decoration. The main text includes the label *ahk'utu'*, lit. 'giving-implement', which indicates that the vases served as central objects in gift-giving observances, and were produced for this purpose (Helmke, 2001: 51–52; see also Graham et al., 1980: 165). The remaining glyphs indicate that the vases were produced for a member of the elite named Lady Olom, who bore some of the most exalted titles, but without any clear indication of a royal title or pedigree (Helmke and Reents-Budet, 2008: 41–43). Helmke (2001) proposed that the Ahk'utu' vases were initially produced for Lady Olom to help consolidate her status and build alliances via gifting at ritual observances such as feasting, with the widespread circulation of the vases eventually resulting in the production of local copies. These copies continued to be produced and distributed via social processes that were similar in practice, and even though they continued to bear the name of Lady Olom these were distributed in different social networks.

2.2. Archaeological contexts

The Ahk'utu' vases have been found at more than two dozen sites across the eastern central Maya lowlands in what is now Belize and Guatemala. The vases included in this study were recovered from eight Belize sites: Altun Ha, Pook's Hill, Baking Pot, Marco Gonzalez, Cahal Pech, Mountain Cow, Zayden Creek, and the Caves Branch sites (Sapodilla Rockshelter and Actun Lubul Ha) (Fig. 2). The vase fragments are mostly found in contexts related to terminal occupational debris, terminal ritual debris, or middens of elite residential structures in these sites (Helmke, 2001: 21–29). It is interesting that, with the exception of Marco Gonzalez, all of the eight sites show evidence of decline, abandonment of use and/or gradual depopulation towards the end of the Classic period (Audet, 2007; Graham and Pendergast, 1989; Healy et al., 1998; Helmke, 2006a, 2006b; Morton, 2010; Pendergast, 1979; Wrobel and Shelton, 2011).

2.3. Geological settings

Most of the Belize landmass is underlain by limestones of different ages, with a general tendency of decreasing age from the southwest to the northeast (King et al., 1992; Wright et al., 1959). The limestones of the Cretaceous formations in the southwest are described as hard, with some limestones contributing to the development of the most striking karstic landscape of the country (King et al., 1992: 26; Wright et al., 1959: 24). On the other hand, the limestones of the Pleistocene-Holocene formations in the northeast are said to be deeply weathered, and display a marl-like characteristic, which is also known as *sascab* (Darch, 1981; Darch and Furley, 1983: 179). An exception to this vast low-lying limestone plain is the Maya Mountains, which occupy the southern part of the country. The geology of the area of the Maya Mountains is characterised by the presence of Paleozoic metasediments and metamorphosed volcanic rocks with granite intrusions (Bateson and Hall, 1977; Shipley and Graham, 1987).

Fig. 1. An Ahku'tu' moulded-carved vase: (a) the vessel profile and (b) a panel showing the iconographic design. Illustration by Christophe Helmke and photograph by Dorie Reents-Budet (after Ting and Helmke, 2013: Fig. 1).

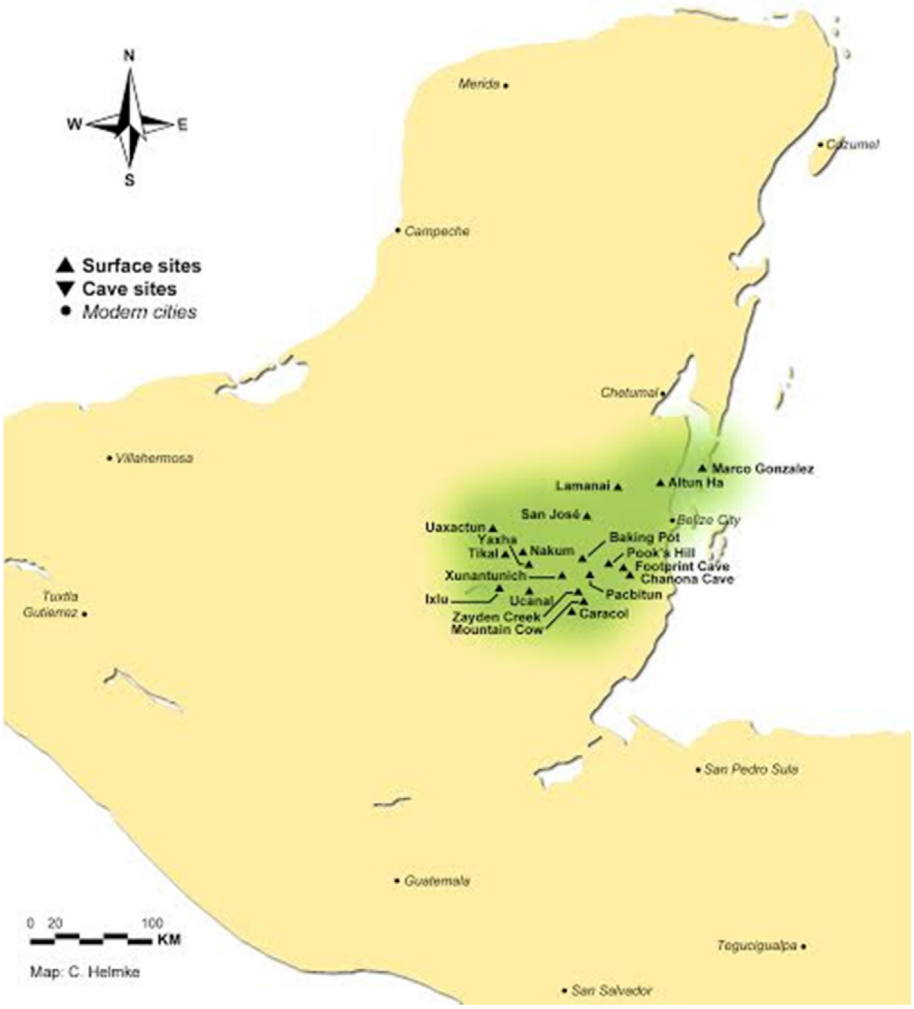

Fig. 2. Map of Maya area showing the distribution sphere of the Ahk'utu' vases in the eastern lowlands, including the sites selected for the study (Map by Christophe Helmke).

3. Methods

A selection of 62 samples of Ahk'utu' vases (Table 1) was analysed by a combination of analytical techniques and statistical methods as described below:

3.1. Thin-section petrography

Thin-section petrography was employed by Ting to identify the mineralogy and texture of the samples (Freestone, 1995; Middleton and Freestone, 1991). Variation in these characteristics led to the definition of fabric groups, which we hypothesise reflect the recipes of different producers or production groups. This method permitted the identification and characterisation of a wide variety of minerals and components, which is important in the case of Belize, where the predominance of limestone has the effect of blurring chemical groupings. With reference to the local geological information, thin-section petrography also facilitated the determination of the provenances of the vases, at least as regards local versus non-local. The description of the thin sections presented here follows Whitbread's (1995) descriptive system.

3.2. Instrumental neutron activation analysis (INAA)

The bulk chemical composition of the samples was characterised by INAA, which was conducted at the Smithsonian

Table 1
The Ahk'utu' samples selected for this study.

Site	No. of sherds recovered	No. of sherds sampled	% Data in the no. of sherds sampled	Remarks
Altun Ha	ca. 180	22	ca. 12%	One of the largest Ahk'utu' assemblages
Pook's Hill	>200	20	ca. 10%	One of the largest Ahk'utu' assemblages
Baking Pot	15	8	ca. 53%	
Marco Gonzalez	5	5	100%	
Cahal Pech	2	2	100%	
Mountain Cow	2	2	100%	
Zayden Creek	1	1	100%	
Actun Lubul Ha	ca. 3	1	33%	On-going research
Sapodilla Rockshelter	1	1	100%	On-going research

Institution (Blackman and Bishop, 2007). The 28 elements detected were Na, K, Ca, Sc, Cr, Fe, Co, Zn, As, Br, Rb, Zr, Sb, Cs, Ba, La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, Hf, Ta, Th, U and W. Multivariate statistics were used to search for patterning in the dataset (Bishop and Neff, 1989), seeking groups that could be cross-referenced with the petrographic data. In particular, principal component analysis (PCA) was executed using the statistical programme SPSS, to calculate the correlation coefficients between variables and establish principal components (Baxter, 2003: 73–83; Shennan, 1997: 265–287). Co, Zn, As, Br, Cs, Ba, Nd and Ta were not included for PCA because: (1) they reflected contamination during the drilling process in preparation of the samples; (2) they were more susceptible to alteration by the firing of ceramics and post-depositional contamination; and/or (3) they did not present any meaningful structure, and instead acted as background 'noise' that obscured the formation of groups. Therefore, the 19 elements that exhibited the clearest grouping tendencies were submitted for PCA.

3.3. Scanning electron microscopy-energy dispersive spectrometry (SEM-EDS)

SEM-EDS was also employed by Ting to examine technological traits of the samples in two ways. The initial examination focused on the microstructure of the fabrics, which was useful in estimating firing temperatures (Maniatis and Tite, 1981; Tite and Maniatis, 1975; Tite et al., 1982; Wolf, 2002). As the second step, it was used to characterise the elemental composition of the slip layer and its associated ceramic matrix (Freestone, 1982). While we acknowledge the increased uncertainty of SEM-EDS analyses of porous, heterogeneous materials such as ceramics, these results proved useful to identify trends that would otherwise not have been observed. The analyses were carried out using two different SEM suites – Hitachi SEM S-3400N and JEOL JXA 8600 Superprobe – at the UCL Institute of Archaeology but accuracy and inter-instrument reproducibility were confirmed through repeat analyses of the same certified reference materials. Both instruments are fitted with Oxford Instruments INCA energy dispersive spectrometer analysis systems. They were set to 20.0 kV in voltage. The working distance was fixed at 10 mm, and the process time of each analysis was set to 5 with deadtime ranging from 26% to 34%. All data were converted to oxides by stoichiometry and normalised to 100 wt% to account for fluctuations in beam intensity and sample porosity.

4. Results

4.1. Compositional variability

The results presented below summarise the INAA data and petrographic descriptions, but all raw data are available on an online repository with meta-data in the Journal of Open Archaeology Data (Ting, 2015).

4.1.1. Fabric groups

Three main fabric groups were identified: the Crystalline Calcite Group, Mixed Carbonate Group, and Volcanic Ash Group. The majority of the samples (n = 47, 76% of the sherds) fall into the Crystalline Calcite Group. These samples contain crystalline calcite as the principal type of inclusion. This group can be further divided into two subgroups based on variations in mineralogy and texture:

Crystalline Calcite Subgroup A, the larger subgroup (n = 42), exhibits considerable internal heterogeneity, with crystalline calcite inclusions that vary greatly in grain sizes (0.08 mm–3.2 mm and no clear mode grain size), relative abundance and sorting (Fig. 3a–c). Three subsets of samples have been tentatively recognised within Subgroup A: (1) with predominance (>70%) of fine sand-sized calcite inclusions, (2) with frequent (30–50%) to common (15–30%) presence of fine sand-sized calcite inclusions, and (3) with dominance (50–70%) of angular medium sand-sized calcite inclusions. Whether the subsets reflect natural variation in clay sources or the involvement of different production groups is discussed in Section 4.1.2.

Crystalline Calcite Subgroup B (n = 5) is characterised by the dominance of crystalline calcite inclusions that are more angular and coarser-grained (mode grain size = 0.56 mm) than those in Subgroup A (Fig. 3d). The presence of chert, chalcedony, iron-rich nodules, and clay pellets in the red clay matrix is also distinctive of Subgroup B.

The Mixed Carbonate Group (n = 3, 5% of the sherds) also contains frequent to common crystalline calcite inclusions, but these samples form a separate group owing to the frequent to few micritic calcite inclusions (*sascab*). Both inclusion types are of medium sand-size (mode grain size = ca. 0.4 mm) and moderately to well sorted (Fig. 4a), and they appear in both calcareous and non-calcareous clays, a feature that points to internal heterogeneity within the group.

The remaining samples (n = 12, 19% of the sherds) belong to the Volcanic Ash Group, which is distinctive owing to the presence of added volcanic ash, rather than crystalline calcite particles, as the predominant type of tempering material. Variations in mineralogy and texture allow the separation of the Volcanic Ash Group samples into three subgroups:

Volcanic Ash Subgroup A (n = 4) can be distinguished from the other two variants on the basis of its diversity in inclusions and coarser grain size. In addition to the predominance of volcanic ash, it displays the frequent occurrence of biotite, as well as the common to very few occurrence of quartz and plagioclase feldspar, all of which are of medium sand size (ca. 0.24 mm–0.32 mm), with some inclusions corresponding to the size of coarse sand (ca. 0.56 mm) (Fig. 4b).

Volcanic Ash Subgroup B (n = 4) differs from Subgroup A as regards the relative abundance and grain size of the inclusions, rather than their mineralogy. Here, volcanic ash temper predominates as well, followed by the common to few biotite and quartz inclusions, and the rare occurrence of plagioclase feldspar (Fig. 4c). The inclusions are finer-grained (ca. 0.16 mm–0.24 mm) than those in Subgroup A.

Finally, Volcanic Ash Subgroup C (n = 4) stands out owing to the sole presence of volcanic ash temper and quartz inclusions, which are both much finer-grained (<0.16 mm) than the previous subgroups (Fig. 4d).

4.1.2. Chemical composition

By plotting the first two principal components after PCA of the INAA subcomposition, three broad clusters of samples can be recognised (Fig. 5), which correspond closely with the petrographic characterisation of the Ahk'utu' samples as described in Section 4.1.1. The majority of the samples cluster at the bottom left quarter of the principal component plot are distinct from the remainder primarily in their higher Ca concentration. With the exception of four samples, all samples in this cluster belong to Crystalline Calcite Subgroup A, with Ca concentration ranging from 10.2% to 26.8% with an average of 17.0% (Table 2). However, further division of the samples of Subgroup A in this cluster with reference to the three petrographic subsets proved to be difficult. As a result, these samples were submitted to additional PCA to explore the possible chemical structure within Subgroup A.

A new PCA was performed on Crystalline Calcite Subgroup A after removal of two outliers (PHMC1 and PHMC13) and normalising the dataset to the sum of the subcomposition of all elements

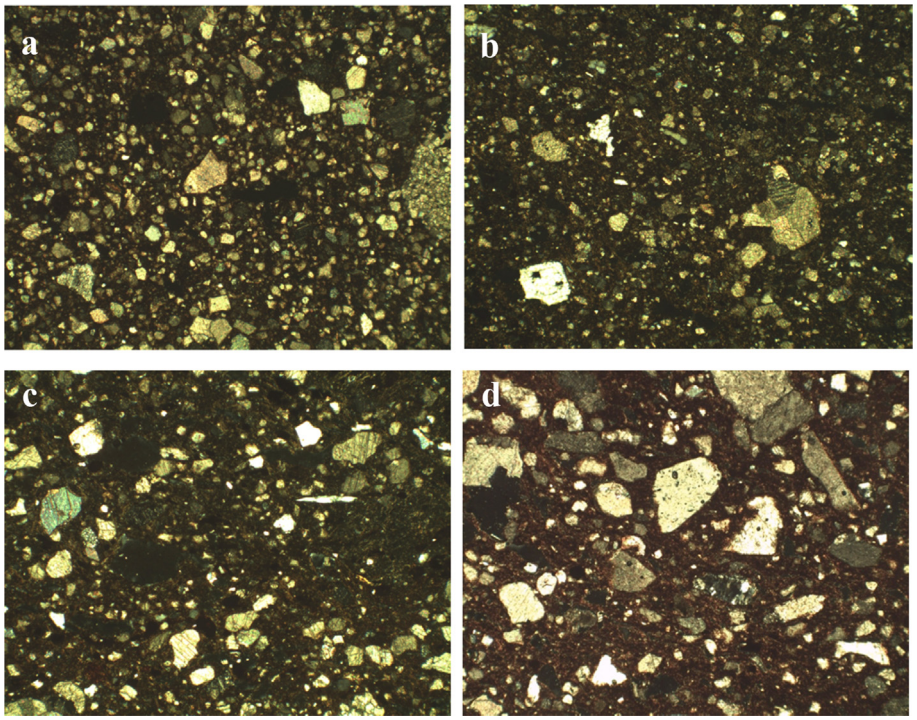

Fig. 3. Photomicrographs of samples from the Crystalline Calcite Group: (a) Subgroup A – predominant fine sand-sized calcite; (b) Subgroup A – frequent to common fine sand-sized calcite; (c) Subgroup A – dominant angular medium sand-sized calcite; and (d) Subgroup B. All photomicrographs in XP at ×50 magnification. Field view = 3 mm.

except Ca. This transformation aimed at reducing the diluting effect of the carbonate temper on the elements associated with the clay matrix. No clear grouping tendencies can be recognised on the resultant PCA plot when the samples are labelled according to their petrographic characteristics only (Fig. 6). Yet, if the information on the sites where the samples were recovered is also taken into account, some trends become apparent (Fig. 6). For instance, the subset of samples characterised by the frequent to common presence of fine sand-sized calcite inclusions is associated with Altun Ha, whereas those with dominant medium sand-sized calcite inclusions are mostly linked to Pook's Hill. Such correlations suggest that the subsets might be the products of use of clay sources local to

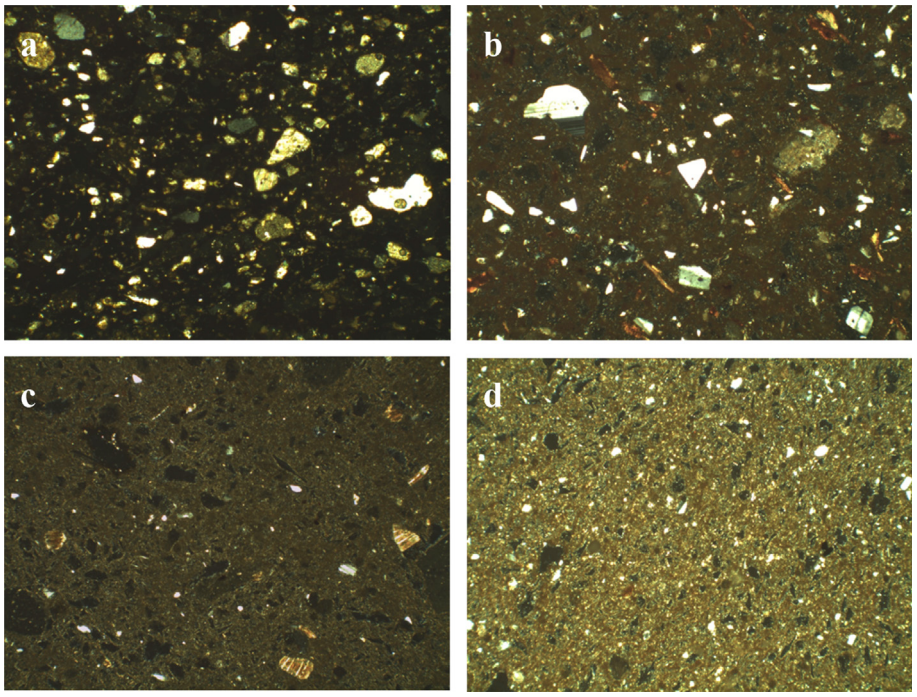

Fig. 4. Photomicrographs of samples from (a) Mixed Carbonate Group; (b) Volcanic Ash Subgroup A; (c) Volcanic Ash Subgroup B; and (d) Volcanic Ash Subgroup C. All photomicrographs in XP at ×50 magnification. Field view = 3 mm.

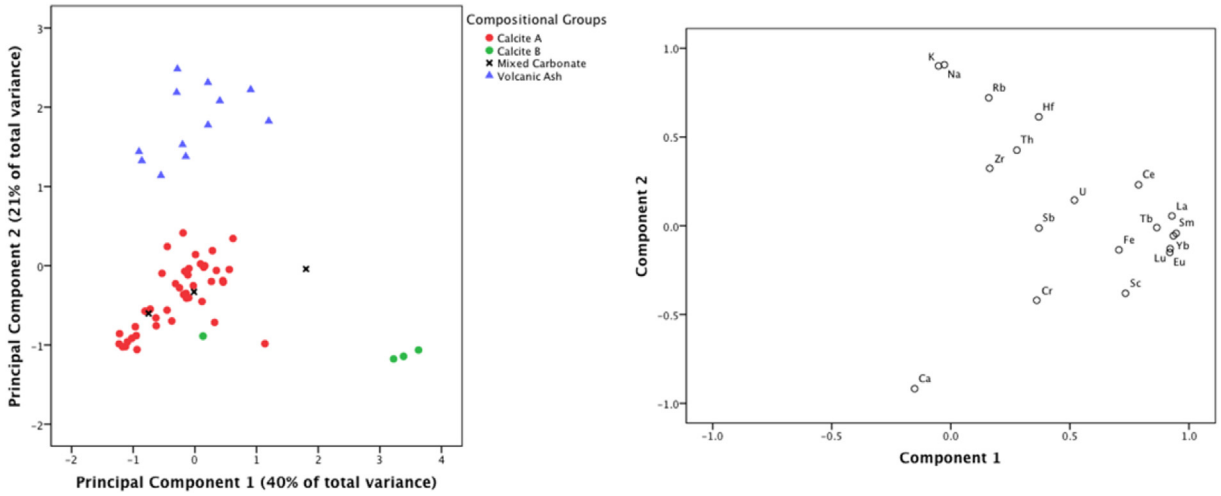

Fig. 5. Principal component plot (left) and loading plot (right) showing the first two principal components, which represent 61% of total variance, of the unaltered INAA data of all Ahk'utu' samples.

Table 2
Summary statistics for selected elements by INAA in accordance to fabric groups. All elements are recorded in ppm.

Compositional groups		Na	K	Ca	Cr	Fe	Rb	La	Sm	Eu	Tb	Yb	Lu
Crystalline	Max.	4780	8890	268,000	141	37,100	118	33	5.69	1.09	0.92	4.18	0.50
Calcite A (n = 42)	Min.	284	3610	102,000	38	15,600	41	18	2.48	0.44	0	1.80	0.28
	Mean	**843**	**5948**	**169,595**	**53**	**23,257**	**76**	**23**	**3.66**	**0.62**	**0.59**	**2.63**	**0.39**
	Stdev	959	1327	39,346	16	4277	18	4	0.7	0.1	0.1	0.5	0.1
	rsd (%)	114	22	23	30	18	23	15	19	20	24	18	15
Crystalline Calcite B (n = 4)[a]	Max.	671	4380	221,000	66	39,700	82	56	12.1	2.12	1.59	5.85	0.93
	Min.	501	3710	165,000	57	35,800	51	18	3.50	0.57	0.47	2.29	0.36
	Mean	**588**	**3973**	**187,250**	**63**	**37,925**	**68**	**46**	**9.58**	**1.69**	**1.27**	**4.82**	**0.74**
	Stdev	71	289	24,391	4	1704	13	19	4.1	0.8	0.5	1.7	0.3
	rsd (%)	12	7	13	6	4	20	41	42	44	42	35	35
Mixed Carbonate (n = 3)	Max.	2790	5970	137,000	87	32,400	68	37	6.28	1.13	0.95	3.83	0.54
	Min.	474	5500	133,000	50	24,500	58	18	2.55	0.45	0.43	2.22	0.42
	Mean	**1250**	**5720**	**134,667**	**65**	**28,300**	**62**	**26**	**4.22**	**0.74**	**0.66**	**2.92**	**0.47**
	Stdev	1334	236	2082	19	3959	6	10	1.9	0.4	0.3	0.8	0.1
	rsd (%)	107	4	2	30	14	9	38	45	47	41	28	13
Volcanic Ash A (n = 4)	Max.	15,300	15,200	71,000	32	29,900	167	28	4.98	0.66	0.65	2.52	0.33
	Min.	12,900	10,400	9710	26	23,400	71	21	2.67	0.48	0.34	1.63	0.28
	Mean	**14,325**	**12,400**	**34,803**	**29**	**25,250**	**98**	**23**	**3.44**	**0.57**	**0.45**	**2.01**	**0.30**
	Stdev	1014	2072	28,964	2	3129	46	3	1.0	0.1	0.1	0.4	0.02
	rsd (%)	7	17	83	8	12	47	14	30	13	31	18	7
Volcanic Ash B (n = 4)	Max.	16,100	20,200	14,300	40	28,500	125	31	5.73	0.83	0.82	3.46	0.46
	Min.	11,800	10,800	0	18	19,800	72	25	3.02	0.49	0.37	1.97	0.29
	Mean	**14,300**	**13,875**	**6550**	**32**	**25,075**	**94**	**28**	**4.17**	**0.64**	**0.60**	**2.61**	**0.35**
	Stdev	1857	4272	7626	10	3723	23	3	1.2	0.1	0.2	0.6	0.1
	rsd (%)	13	31	116	30	15	24	10	28	23	32	24	20
Volcanic Ash C (n = 4)	Max.	13,800	18,800	59,400	67	30,200	143	31	6.01	0.98	1.08	3.92	0.59
	Min.	9730	14,800	0	28	19,100	136	26	4.72	0.68	0.72	3.21	0.45
	Mean	**11,833**	**16,575**	**21,975**	**40**	**22,025**	**141**	**29**	**5.29**	**0.79**	**0.93**	**3.55**	**0.51**
	Stdev	2018	1863	28,337	18	5454	3	3	0.6	0.1	0.2	0.3	0.1
	rsd (%)	17	11	129	46	25	2	9	11	17	17	8	12

[a] The measurement of the bulk chemical composition of BPMC4 is not available owing to problems with counting.

each site, or at least that the communities at Altun Ha and Pook's Hill preferred Ahk'utu' vases produced by workshops with distinctive ways of preparing the raw materials. In addition, the samples from Marco Gonzalez, which share petrographic characteristics with those in the subset of predominant fine sand-sized calcite, appear to be separated chemically from other samples in the same petrographic subset. Likewise, the two samples from Cahal Pech appear as chemical outliers of their relevant petrographic subsets. These findings suggest that different clays were used, and that these were most likely extracted from local sources, although comparison with local clay resources is warranted to verify this hypothesis.

It is worth noting that the three samples belonging to the Mixed Carbonate Group are positioned among the samples of Subgroup A on the principal component plot (Fig. 5). Like the samples of Subgroup A, these samples also have high Ca concentration, which ranges from 13.3% to 13.7% with an average of 13.5% (Table 2).

Turning to the cluster in the bottom right quarter of the principal component plot (Fig. 5), this consists of only three samples, all of which belong to the Crystalline Calcite Subgroup B. These samples are characterised by Ca concentration as high as those in Subgroup A, ranging from 16.5% to 18.8% with a mean value of 17.6%

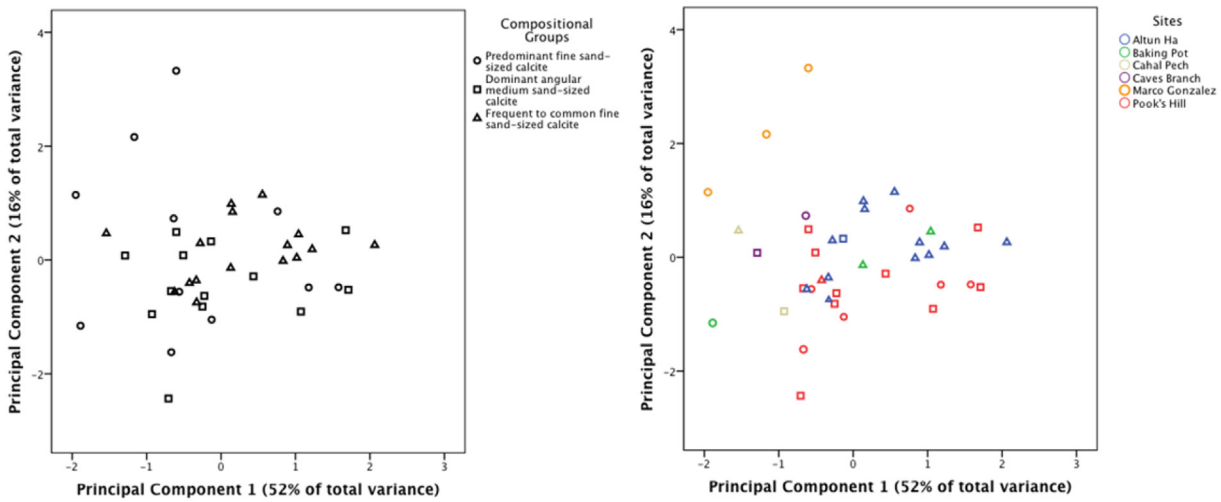

Fig. 6. Principal component plots of (left) Ca-normalised samples of Subgroup A; and (right) the correlation of bulk chemical composition, petrographic data, and sites of recovery.

(Table 2), but with higher concentrations of such minor and trace elements as Cr, Fe, La, Sm, Eu, Tb, Yb, and Lu. In particular, the Fe concentration of Subgroup B averages 3.8% (compared to 2.3% in Subgroup A), which contributes to the red colouration of the clay matrix noted petrographically. It is worth noting that one sample (AHMC21) from petrographic Subgroup B plots closer to the cluster of samples belonging to Subgroup A on the principal component plot. One possible explanation is that this sample was made of clay similar to those of Subgroup A, but tempered according to the method characteristic of Subgroup B.

The remaining cluster of samples (n = 12) plots on the top half of the principal component plot and includes all the sherds in the Volcanic Ash Group. Unlike the previous two clusters, these samples have remarkably lower Ca concentration, ranging from 0.9% to 7.1% with an average of 2.1%. Conversely, they display higher Na, K, and Rb levels. In particular, the mean values of Na and K of these samples are 1.3% and 1.4% respectively – an order of magnitude higher than the calcite samples in the other two clusters (Table 2). The addition of volcanic ash rather than crystalline calcite as tempering material is the likely explanation for the low Ca concentration, and the higher alkali levels (Table 3).

Overall, petrographic and chemical data are complementary in the recognition and characterisation of six compositional groups – namely Crystalline Calcite Subgroups A and B, Mixed Carbonate Group, and Volcanic Ash Subgroups A, B and C – among the Ahk'utu' samples. If the petrographic dataset had been considered alone, it would not have been possible to establish the correspondence between the subsets of samples with closer chemical signatures and particular sites of recovery. On the other hand, if the chemical data were used alone, it would be difficult to identify the Mixed Carbonate Group as different from Crystalline Calcite Subgroup A, as well to establish the division of the Volcanic Ash Group into three subgroups.

Table 3
Elemental composition of volcanic ash inclusions by SEM-EDS. All data represent an average of at least three analyses and are normalised to 100%.

Samples	Na_2O	Al_2O_3	Si_2O	K_2O	CaO	FeO
AHMC26	0.5	13.9	80.2	2.5	1.5	1.4
AHMC32	0.5	12.6	83.3	2.0	0.6	1.0
AHMC33	0.6	12.2	82.0	3.0	1.0	1.1
BPMC9	0.6	12.2	82.3	2.7	1.0	1.2
MTMC1	0.9	12.6	81.2	2.3	1.0	1.4

4.2. Technological variability

4.2.1. Slip composition and the order of slipping and carving

Although the slip appears to have been worn post-depositionally in some cases, the presence of yellowish red (5YR 5/8) or reddish yellow (5YR 6/8) slip was observable on 17 samples, including three from the Volcanic Ash Group, one from the Mixed Carbonate Group and 13 from Crystalline Calcite Subgroup A. As suggested in their name 'moulded-carved', these vessels were purportedly first moulded, followed by slipping and gouge-incision for surface finishing. Yet, the step of the manufacturing sequence at which the slip was applied varies between the calcite and volcanic ash-tempered vases. For the calcite vases, the sharp edges along the incised lines and a lack of slip in the troughs of lines, as observed under the stereomicroscope, point to the execution of gouge-incision after the slip was applied and the vessels were dried to leather-hard. The order of slipping and carving is reversed for the volcanic ash-tempered vases, which were gouged and incised before the application of slip, as evident in the rounder edges along the incised lines and the presence of slip both in the trough and on the ridge of incised lines. Despite the differences in the order of slipping and carving, the slips of the calcite and volcanic ash-tempered vases share similar microscopic and compositional characteristics.

At the microscopic level, the slip layer of all samples is identifiable owing to its high optical activity, which alters from reddish brown to dark red (in the web version) upon rotation in the polarising microscope (Fig. 7a and b). The slip is also recognisable as a homogenous layer with partially vitrified structure with few or no inclusions under the SEM. The thickness of slip layers typically ranges from 15 to 20 μm, reaching 50 μm in some samples, with a clear interface between this layer and the ceramic matrix (Fig. 7c and d). All evidence indicates that the slip was an additional layer applied to the exterior surface of the vases rather than the result of burnishing the surface of pottery to create the self-slip effect.

The EDS analysis of the slip layers and their associated ceramic matrix devoid of inclusions reveals that slight but systematic variations exist in the composition of slip layers and their associated ceramic matrix (Table 4). Such variations are likely to be reflective of the effects of the preparation process involved, rather than the use of completely different clays for slip and paste. Both the slips and their associated ceramic matrix have low CaO levels denoting the use of non-calcareous clays for both, but the slips stand out by virtue of their high FeO concentration (ranging from 5.5% to 16.0%, with a mean value of 9.5%, compared to 5.6% in the bodies). The

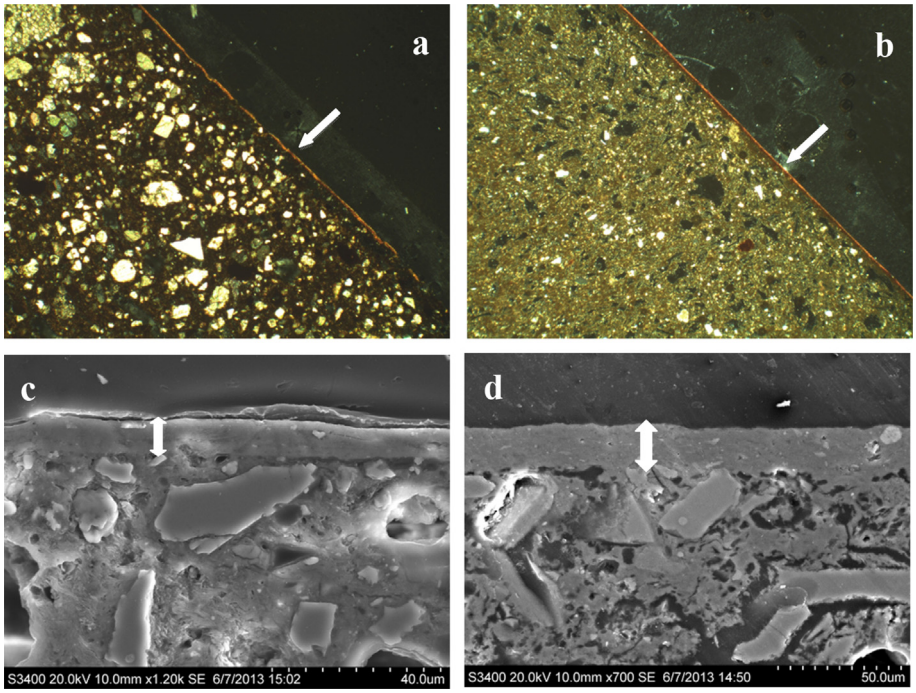

Fig. 7. Photomicrographs showing the presence of slip layer (indicated by arrows) of (a) calcite sample and (b) volcanic ash-tempered sample under polarising microscope. SE images showing the presence of slip layer (indicated by arrows) of (c) a calcite sample and (d) a volcanic ash-tempered sample under the SEM.

Table 4
Normalised SEM-EDS data of the elemental composition of the slips and their associated ceramic matrices. The data shown here represent an average of at least 3 analyses of the slip and ceramic matrix of each sample.

Samples	Fabric group		MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	FeO
AHMC6	Calcite A	slip	0.8	31.0	55.5	0.6	2.7	1.1	7.7
		paste	0.3	33.7	54.5	2.0	3.5	0.9	4.5
AHMC9	Calcite A	slip	1.0	29.5	57.7	0.5	2.9	0.8	6.9
		paste	0.6	25.9	62.4	1.6	2.8	1.0	5.3
AHMC13	Calcite A	slip	1.0	31.1	51.6	1.4	3.5	0.9	9.7
		paste	0.5	35.0	51.1	1.9	3.2	1.0	6.7
BPMC2	Calcite A	slip	1.5	28.4	57.2	0.6	2.0	0.9	9.3
		paste	0.4	30.9	58.2	1.9	3.2	0.6	4.9
CPMC1	Calcite A	slip	1.0	27.3	59.1	0.8	3.0	1.0	7.8
		paste	0.4	27.9	61.8	1.6	3.0	0.8	4.5
MGMC1	Calcite A	slip	2.7	28.9	53.9	0.9	2.3	0.9	10.4
		paste	1.4	32.0	54.3	2.6	1.8	1.3	6.0
MGMC2	Calcite A	slip	2.3	31.4	53.1	1.0	3.0	1.1	8.2
		paste	1.3	32.9	54.2	2.4	2.2	0.8	5.7
MGMC5	Calcite A	slip	2.6	25.9	55.0	1.0	2.8	1.4	11.2
		paste	1.4	29.4	58.4	2.6	1.4	1.3	4.8
PHMC3	Calcite A	slip	2.8	30.2	52.0	2.3	1.8	1.3	9.7
		paste	0.7	33.0	53.9	1.7	3.4	1.5	5.8
PHMC9	Calcite A	slip	0.6	35.3	51.3	0.5	2.5	1.2	9.0
		paste	0.6	33.4	52.4	1.2	3.8	1.2	7.5
PHMC11	Calcite A	slip	1.4	30.9	48.0	0.3	2.5	0.9	15.8
		paste	0.6	33.0	53.4	1.9	2.9	1.0	6.4
SDRMC1	Calcite A	slip	2.0	26.0	58.2	0.9	4.2	1.1	7.7
		paste	0.7	30.9	56.4	2.6	2.7	0.7	5.9
WFCMC1	Calcite A	slip	3.5	28.3	52.3	0.9	5.2	1.6	8.2
		paste	1.5	25.5	60.6	1.4	4.1	0.8	6.1
PHMC4	Mixed	slip	0.8	32.0	52.6	0.6	1.9	1.1	11.0
	Carbonate	paste	0.7	36.1	51.2	1.7	2.7	1.2	6.6
AHMC3	Volcanic A	slip	0.4	25.2	56.2	0.4	3.4	0.8	5.5
		paste	0.7	22.3	52.7	0.5	6.0	1.0	5.6
MTMC1	Volcanic B	slip	1.1	31.3	53.9	1.0	3.1	1.6	8.1
		paste	1.1	18.4	70.3	2.0	3.5	0.8	4.1
BPMC9	Volcanic C	slip	1.2	20.7	55.6	3.1	3.0	0.6	16.0
		paste	0.9	16.8	67.3	3.8	6.4	0.5	4.0

higher FeO concentration in the slips could be achieved by several methods, including the use of fine clay suspensions, the intentional addition of natural iron oxides, and/or the selection of clays naturally richer in FeO (Papachristodoulou et al., 2010: 2152).

In addition to high FeO, the slips show lower concentrations of Al_2O_3, SiO_2, K_2O, and CaO. The depletion of the SiO_2 and CaO concentrations is probably explained by the deliberate removal of coarse-grained quartz and calcite inclusions to increase the fineness of the clay for slipping. In particular, the low CaO concentration, combined with firing in an oxidising atmosphere especially at the final stage, would have encouraged the development of the yellowish red or reddish yellow slip characteristic of the Ahk'utu' vases. It is interesting, however, to note that the K_2O concentration of the slips is lower than that of the bodies, which argues against the use of K-rich clays to promote the sintering of slips, as documented elsewhere (see Papachristodoulou et al., 2010; Perez-Arantegui and Castillo, 2000).

4.2.2. Firing conditions

The atmosphere and temperature of firing were assessed through the macroscopic observation of paste colour, as well as the examination of the microstructure of fresh fractures by SEM. The majority of the calcite vases have bright paste colours that range from reddish yellow (5YR 6/6 to 5YR 6/8) to red (2.5YR 5/6), suggesting that the vessels were fired in an oxidising atmosphere. The presence of dark firing cores of varying thickness in some of the samples indicates, however, that the process of oxidation was incomplete. In a few cases, the calcite vases were fired in reducing atmospheres, as reflected in their very dark grey (5YR 3/1) paste. Whether fired in an oxidising or a reducing atmosphere, their firing temperatures did not exceed 750 °C. This conclusion is based on an absence of signs of vitrification such as the development of glassy phase and bloating pores (Maniatis and Tite, 1981: 61–64), as well as a lack of decomposition of calcite grains as shown in the secondary electron images (Fig. 8) (Maggetti, 1982). Low firing temperatures, coupled with varying redox, suggest that potters had

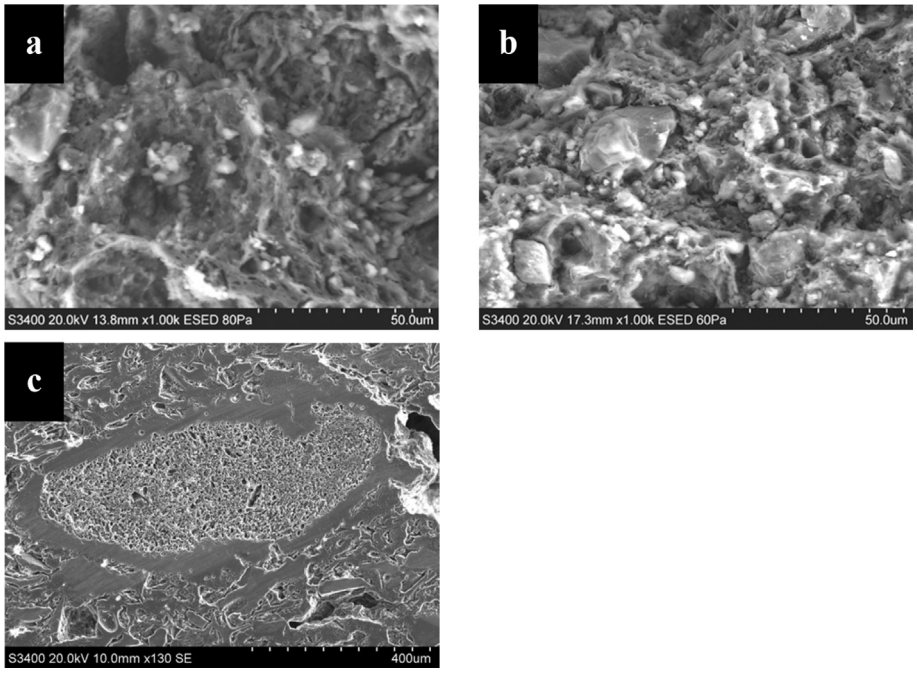

Fig. 8. SE images of (a) calcite sample showing the flaky structure of clay minerals; (b) volcanic ash-tempered sample showing the development of small bloating pores; (c) volcanic ash-tempered sample showing the development glassy phase at the interface of volcanic ash and clay matrix.

little firing atmosphere control for the calcite vases (see Ball, 1993).

In contrast, the homogeneous pink (7.5YR 7/4) paste characteristic of the volcanic ash-tempered vases suggests that these vessels were fired in an atmosphere that produced complete oxidation. The firing temperatures of these vases are estimated to have been slightly higher than the calcite ones, perhaps ranging between 750 °C and 800 °C, as suggested by the presence of isolated patches of glassy phase and fine bloating pores (Fig. 8b).

The process of vitrification was neither extensive nor continuous (Maniatis and Tite, 1981: 61–64). The incomplete vitrification of the volcanic ash-tempered vases is confirmed by the development of glassy phase particularly at the interface between the volcanic ash inclusions and the ceramic matrices in two samples (Fig. 8c). The elemental composition of this glassy phase falls between that of the volcanic ash and the clay matrix. This finding suggests that volcanic ash inclusions may have acted locally as fluxes, promoting vitrification and hence the overall hardness and homogeneity of the end product (cf. Villaseñor and Graham, 2010). Such attempts at initiating vitrification suggest that either potters had greater control over the firing process, or they might have been aware of the advantage of volcanic ash tempers when pots were fired to temperatures high enough for some vitrification to take place as volcanic ash tempers were used throughout the Late Classic (see Jones, 1986).

5. Discussion

5.1. Potential provenances of the Ahk'utu' vases

With reference to geological information, it is possible to suggest the potential sources of the six compositional groups that were involved in the production of the Ahk'utu' vases.

5.1.1. Crystalline Calcite Subgroup A

With the vast majority of Belize being underlain by limestone, as well as the common use of calcite ceramic pastes over time and space (e.g. Howie, 2012: 60–86; Sunahara, 2009: 45–49), the establishment of the materials used in the production of vases of Crystalline Calcite Subgroup A is not straightforward. Yet, judging from the correlation among the bulk chemical composition, petrographic characteristics, and the site of recovery as illustrated in Section 4.1.2, we postulate that the vases in Subgroup A were produced at multiple locations, presumably local to the sites where they were recovered. An exception to this hypothesis is the vases of Marco Gonzalez, which are most likely to have been imported from mainland Belize rather than locally manufactured, a proposal that would accord with the site's function as a trading depot (Graham and Pendergast, 1989; Ting, 2013). In addition, at least to date no clay resources have been located on Ambergris Caye (King et al., 1992: 188–189).

5.1.2. Crystalline Calcite Subgroup B

The raw materials used to produce the vases of Crystalline Calcite Subgroup B are highly consistent with the geology of Altun Ha and its adjacent area in the coastal plain east of the New River, which is underlain by limestones of Cayo and Doubloon Bank formations. These limestones are characterised by the presence of chert, brought about by the Northern Belize Chert-Bearing Zone (Cackler et al., 1999; Hester and Shafer, 1984; Wright et al., 1959), which might have contributed to the chert and chalcedony in the ceramic paste when limestones were crushed for temper. The clays could have been obtained from the reddish brown old siliceous alluvial deposits, categorised as Boom Subsuite soils by King et al. (1992: 74–75, 203–204), located west of the site. All evidence suggests that the production of these vases was probably local to Altun Ha, with the possible exception of sample AHMC21 (see above, Section 4.1.2.).

5.1.3. Mixed Carbonate Group

The addition of micritic calcite inclusions to the vases of the Mixed Carbonate Group points to a potential source in northern Belize. The region of northern Belize, which is underlain by micritic calcite deposits of the New Town Formation and Orange Walk Group (Darch 1981; Darch and Furley, 1983). We further postulate

that Lamanai might be responsible for the production of at least some of these vases, particularly with reference to the results of the analysis of the raw materials available in the area that borders the site by Howie (2012). The mineralogical constituents of the Mixed Carbonate Group fabric are consistent with the raw material samples collected from the area east of Structure N10-9 at Lamanai, where the presence of weathered limestones interbedded with harder limestone fragments characteristic of the Yalbac Subsuite soils is reported (Howie, 2012: 74–79, Table 5.1).

5.1.4. Volcanic Ash Group

The volcanic ash tempers added to the vases were unaltered, retaining all the characteristic shapes and isotropic properties of fresh ash (Ford and Glicken, 1987; Ford and Spera, 2007; Shepard, 1964: 29–380; Jones, 1986: 55–85). This rules out the Paleozoic welded tuff of the Maya Mountains, and the Orange Walk lens, as possible sources of temper, leaving airborne ash deposits and the importation of volcanic ash from the Highlands as the potential sources of ash temper. However, without more detailed chemical characterisation of ash particles by SEM-EDS or EPMA, it is difficult to offer further provenance suggestions.

Although the source of the ash temper is yet to be determined, the presence of biotite, quartz and plagioclase feldspar in the vases of Volcanic Ash Subgroups A and B is consistent with the geology of the Bladen Volcanic Member of the Santa Rosa Group, which comprises volcanic rocks rich in quartz and feldspar phenocrysts, and mica-bearing granites (Bateson and Hall, 1977: 14). Although the vases of both Subgroups A and B might be associated with the Maya Mountains area, it is worth noting that they were products of two separate production groups. This argument is based on the textural variation in the fabric characteristic of both subgroups, which is reflective of the different methods employed by potters in preparing the ceramic pastes. On the other hand, the fineness of the Subgroup C fabric makes the determination of the potential provenance even more problematic. Because Ahk'utu' ceramics functioned as integral parts within a widespread network of giving, the primary means of distribution was as finished products, yet the volcanic ash is also extraneous to the geology of the lowlands, an indication of exchange mechanisms involving the raw materials.

5.2. Reconstruction of the craft organisation

Our study allows us to establish that two main ceramic traditions co-existed in the production of the Ahk'utu' moulded-carved vases. Although both traditions aimed at producing vases that are visually similar, they differ as regards the types of raw materials used, surface finishing method, and firing regimes (Fig. 9). One tradition (n = 50) involves the use of calcite temper of varying types, sizes, and abundance in preparing the ceramic paste (calcite tradition), whereas the other (n = 12) emphasises the importance of volcanic ash as the principal type of tempering material (volcanic ash tradition). Each tradition has its own distinctive surface finishing method, especially as regards the order of slipping and carving. The overall firing regimes of the vases in these two traditions are also different: the vases in the calcite tradition were fired at lower temperatures in an atmosphere that ranged from relatively complete oxidation to incomplete oxidation, and even to reduction in some cases, whereas those in the volcanic ash tradition were generally fired at higher temperatures in which the process of oxidation was completed.

Although these two broad ceramic traditions probably guided the selection of tempering materials and the main choices of manufacturing techniques, there appears to have been some liberty in the execution of the actual production processes, resulting in the presence of six compositional groups, each with its own distinctive ceramic recipe. The ceramic recipes are not, however, exclusive to a particular producer or production group, as evident in the samples of Crystalline Calcite Subgroup A. This co-existence of multiple producers within each compositional group may have added further variability and thus, in part at least, it have contributed to the high relative standard deviations in the bulk chemical composition of each group (Table 2). This finding therefore suggests that the calcite and volcanic ash ceramic traditions are representative of a flexible framework, rather than a rigid system, which allowed potters to procure local resources and adapt them to the methods of forming, finishing and firing that were characteristic of their respective learning tradition or preference.

5.3. Intra- and inter-site distribution pattern

Examination of the compositional variability of the samples across sites makes it clear that none of the compositional groups was exclusive to a particular site, but also that the diversity of the Ahk'utu' assemblages varies from site to site (Table 5). In sites such as Altun Ha, Baking Pot and Marco Gonzalez, the Ahk'utu' vases were derived from multiple production groups. This contrasts sharply with other sites, including Pook's Hill, Cahal Pech, Caves Branch, Mountain Cow, and Zayden Creek, where the Ahk'utu' vases were largely or exclusively obtained from local sources.

Reference to the potential geological origins of the compositional groups makes it possible to differentiate local from non-local vases. Altun Ha and Baking Pot acquired vases from multiple local

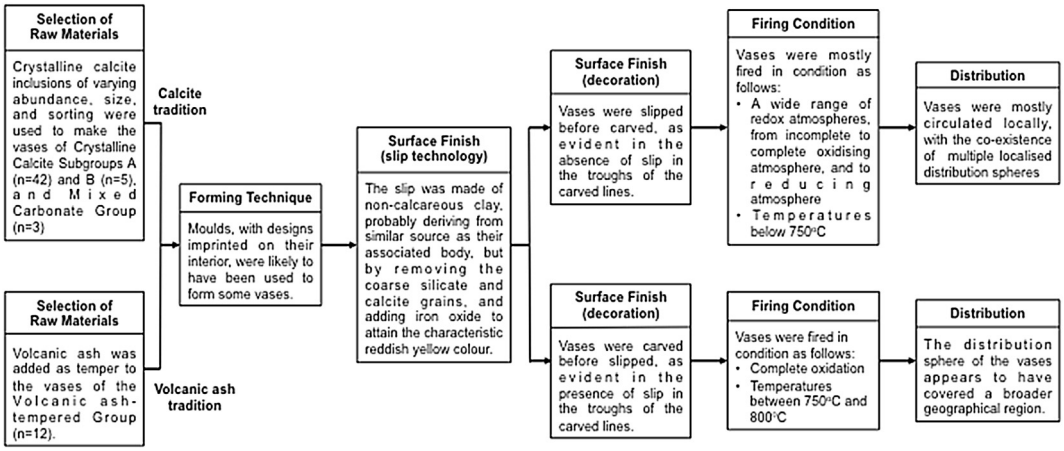

Fig. 9. The production sequence of Ahk'utu' moulded-carved vases (after Ting, 2013: 270, Fig. 10.4).

Table 5
The intra- and inter-site distribution of the samples of the Ahk'utu' vases according to different compositional groups.

Compositional groups	Altun Ha	Baking Pot	Cahal Pech	Caves Branch	Mountain Cow	Marco Gonzalez	Pook's Hill	Zayden Creek
Calcite A	13	3	2	2		3	19	
Calcite B	4	1						
Mixed Carbonate		1				1	1	
Volcanic A	2	1						1
Volcanic B	2				2			
Volcanic C	1	2				1		
Total	22	8	2	2	2	5	20	1

and non-local sources. Both calcite and volcanic ash-tempered vases were found at Altun Ha, with the calcite vases coming from two local sources (Crystalline Calcite Subgroups A and B), and the volcanic ash-tempered ones derived from three non-local sources (Volcanic Ash Subgroups A, B and C) originating from the Maya Mountains area and beyond (Ting et al., 2014:59–60). Similarly, the vases found at Baking Pot were derived from several sources, including one local (Crystalline Calcite Subgroup A) and four non-local sources, which are likely to be related to Altun Ha (Crystalline Calcite Subgroup B), Lamanai (Mixed Carbonate Group), and the Maya Mountains area and beyond (Volcanic Ash Subgroups A and C).

As is the case with Altun Ha and Baking Pot, vases from various sources contributed to the Ahk'utu' assemblage recovered from Marco Gonzalez, where all vases appear to be of foreign origin. Apart from the sample with a ceramic paste characteristic of the Mixed Carbonate Group, which might be connected to Lamanai, the provenances of the vases that were placed into Crystalline Calcite Subgroup A and Volcanic Ash Subgroup C remain undetermined.

On the other hand, Pook's Hill appears to have relied on a single, probably local, source (Crystalline Calcite Subgroup A), for its supply of vases, despite being the location of one of the larger Ahk'utu' assemblages in the eastern lowlands. Likewise, the presence of vases deriving from a single source, whether it was local or non-local, marks Cahal Pech, the Caves Branch sites, Mountain Cow, and Zayden Creek. Yet, the apparent lack of compositional diversity of the Ahk'utu' assemblages from these sites might be attributable to small sample size.

Taken together, the ash-tempered vases appear to have been exchanged by communities – including Altun Ha, Baking Pot, Mountain Cow, and Zayden Creek – over a wide area in the eastern lowlands. In contrast, the exchange sphere of the calcite vases appears more localised, even though these vases were found in the majority of sites.

6. Conclusion

This study has contributed to a better understanding of the production and exchange of fine wares – as represented by the Ahk'utu' vases – in the Maya lowlands during the transition from the Classic to Postclassic period. It is our hope that this study demonstrates how the compositional and technological study of ceramics can offer a new perspective on the nature and development of the transformations that occurred in the Maya lowlands from the 9th century onwards, building on the existing epigraphic and iconographic evidence (see Stuart, 1993). Based on the results, we propose that at least two ceramic traditions are represented, namely the calcite tradition and the volcanic ash tradition. These traditions not only loosely guided the production of Ahk'utu' vases, permitting the presence of multiple producers and liberty in the execution of certain aspects of technical practices, but were also reflected in different distribution patterns. The vases of the calcite tradition were largely circulated locally, whereas those of the volcanic ash tradition seem to be exchanged over a broader geographic region. With this mind, the production and exchange of the vases of the calcite tradition can be considered as attempts by local elites to consolidate their power by using their own means. On the other hand, the production and exchange of the vases from the volcanic ash tradition can be interpreted as evidence of alliance building among elites from different communities. The co-existence of the two ceramic production and exchange traditions, and their internal variants, suggests that there was greater flexibility and fluidity in the maintenance of the socio-political structure in the Maya lowlands from the 9th century and onwards (Graham, 2006). This flexibility and fluidity inferred from the ceramic study would have facilitated the restructuring of social and cultural values and levelling of social pyramids, rather than a collapse that entailed rapid decline or abandonment.

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References

Adams, R.E.W., 1973. Maya Collapse: transformation and termination in the ceramic sequence at Altar de Sacrificios. In: Culbert, T.P. (Ed.), The Classic Maya Collapse. University of New Mexico Press, Albuquerque, pp. 133–164.
Aimers, J.J., 2004. Cultural Change on a Temporal and Spatial Frontier: Ceramics of the Terminal Classic to Postclassic Transition in the Upper Belize River Valley. Archaeopress, Oxford.
Aimers, J.J., 2007a. What maya collapse? Terminal Classic variation in the Maya lowlands. J. Arch. Res. 15, 329–377.
Aimers, J.J., 2007b. The curse of the ware: using ceramic systems in Belize. Res. Rep. Belizean Archaeol. 4, 101–110.
Audet, C.M., 2007. Political Organisation in the Belize Valley: Excavations at Baking Pot, Cahal Pech and Xunantunich. Ph.D. Dissertation. Department of Anthropology, Vanderbilt University, Nashville.
Ball, J.W., 1993. Pottery, potters, palaces, and polities: some socioeconomic and political implications of Late Classic Maya ceramic industries. In: Sabloff, J.A., Henderson, J.A. (Eds.), Lowland Maya Civilization in the Eighth Century A.D. Dumbarton Oaks Research Library and Collection, Washington, D.C, pp. 243–272.
Bateson, J.H., Hall, I.H.S., 1977. The Geology of the Maya Mountains, Belize, Institute of Geological Sciences. Natural Environmental Research Council, Her Majesty's Stationery Office, London.
Baxter, M.J., 2003. Statistics in Archaeology. Wiley-Blackwell, London.
Bishop, R.L., Neff, H., 1989. Compositional data analysis in archaeology. In:

Allen, R.O. (Ed.), Archaeological Chemistry IV, Advances in Chemistry Series 220. American Chemical Society, Washington D.C, pp. 57–86.
Blackman, M.J., Bishop, R.L., 2007. The Smithsonian-NIST partnership: the application of instrumental neutron activation analysis to archaeology. Archaeometry 49 (2), 321–341.
Cackler, P.R., Glascock, M.D., H., N., Iceland, H., Pyburn, K.A., Hudler, D., Hester, T.R., Mitchum Chiarulli, B., 1999. Chipped stone artefacts, source areas, and provenance studies of the Northern Belize Chert-Bearing Zone. J. Arch. Sci. 26 (4), 389–397.
Culbert, T.P., 1973. The Classic Maya Collapse. University of Mexico Press, Albuquerque.
Darch, J.P., 1981. The characteristics and origins of sascab in Northern Belize, Central America. Z. Geomorphol. 25, 400–419.
Darch, J.P., Furley, P.A., 1983. Observations on the nature of sascab and associated soils in Cayo and Orange Walk Districts, Belize and in El Peten, Guatemala. In: Robinson, G.M., Furley, P.A. (Eds.), Resources and Development in Belize: an Account of the University of Edinburgh Expedition to Central America, 1981. Department of Geography, University of Edinburgh, Edinburgh, pp. 179–221.
Demarest, A.A., 1997. The Vanderbilt Petexbatun Regional Archaeological Project 1989–1994: overview, history and major results of a multidisciplinary study of the classic Maya Collapse. An. Meso 8, 209–277.
Demarest, A.A., 2006. The Petexbatun Regional Archaeological Project: a Multidisciplinary Study of the Maya Collapse, Volume I. Vanderbilt Institute of Mesoamerican Archaeology, Vanderbilt University Press, Nashville.
Demarest, A.A., Rice, P.M., Rice, D.S., 2004. The Terminal Classic in the Maya Lowlands: Collapse, Transition, and Transformation. University Press of Colorado, Boulder.
Ford, A., Glicken, H., 1987. The significance of volcanic ash tempering in the ceramics of the central Maya lowlands. In: Rice, P.M., Sharer, R.J. (Eds.), Maya Ceramics: Papers from the 1985 Maya Ceramic Conference, pp. 479–502. BAR International Series 345(ii), B.A.R.: Oxford.
Ford, A., Spera, F., 2007. Fresh volcanic glass shards in the pottery sherds of the Maya lowlands. Res. Rep. Belizean Archaeol. 4, 111–118.
Freestone, I., 1982. Applications and potential of electron probe micro-analysis in technological and provenance investigations of ancient ceramics. Archaeometry 24 (2), 99–116.
Freestone, I., 1995. Ceramic petrography. Am. J. Arch. 99, 111–115.
Freidel, D.A., 1992. Children of the first Father's skull: Terminal Classic warfare in the northern Maya lowlands and the transformation of kingship and elite hierarchies. In: Chase, D.Z., Chase, A.F. (Eds.), Mesoamerican Elites: an Archaeological Assessment. University of Oklahoma Press, Norman, pp. 99–117.
Gifford, J.C., 1976. Prehistoric Pottery Analysis and the Ceramics of Barton Ramie in the Belize Valley, Memoirs of the Peabody Museum of Archaeology and Ethnology, vol. 18. Harvard University, Cambridge.
Graham, E., 2006. An ethnicity to know. In: Sachse, F. (Ed.), Maya Ethnicity: the Construction of Ethnic Identity from Preclassic to Modern Times, Acta Mesoamericana, 19. Verlag Anton Saurwein, Markt Schwaben, pp. 109–124.
Graham, E., McNatt, L., Gutchen, M.A., 1980. Excavations in Footprint Cave, caves branch, Belize. J. Field Arch. 7 (2), 153–172.
Graham, E., Pendergast, D.M., 1989. Excavations at the marco gonzalez site, ambergris Cay, Belize 1986. J. Field Arch. 16 (1), 1–16.
Healy, P.F., Awe, J.J., Helmuth, H., 1998. An ancient Maya multiple burial at Caledonia, Cayo District, Belize. J. Field Arch. 25 (3), 261–274.
Helmke, C.G.B., 2001. The Last Supper: Competitive Feasting and the Terminal Classic Moulded-carved Ceramic Tradition in the Central Maya Lowlands. Unpublished MA Dissertation. Institute of Archaeology, University College London, London.
Helmke, C.G.B., 2006a. A summary of the 1999–2000 seasons of archaeological investigations at Pook's Hill, Cayo District, Belize. Res. Rep. Belizean Archaeol. 3, 173–191.
Helmke, C.G.B., 2006b. Recent investigations into ancient Maya domestic and ritual activities at Pook's Hill, Belize. Pap. Inst. Arch. 17, 77–85.
Helmke, C.G.B., Colas, P.R., Awe, J.J., 1998. Comments on the typology, epigraphy, and iconography of the Actun Tunichil Muknal vase and Belize valley modeled-carved vessels. In: Awe, J.J. (Ed.), The Western Belize Regional Cave Project: a Report of the 1997 Field Season. Department of Anthropology, Durham, pp. 93–140. Occasional Paper No. 2, University of New Hampshire.
Helmke, C., Reents-Budet, D., 2008. A Terminal Classic moulded-carved ceramic type of the eastern Maya lowlands. Res. Rep. Belizean Archaeol. 5, 37–49.
Hester, T.R., Shafer, H.J., 1984. Exploitation of chert resources by the ancient Maya of Northern Belize. World Arch. 16, 157–173.
Howie, L.A., 2012. Ceramic Change and the Maya Collapse: a Study of Pottery Technology, Manufacture and Consumption at Lamanai. Archaeopress, Belize (Oxford).
Jones, L.D., 1986. Lowland Maya Pottery: the Place of Petrological Analysis. B.A.R, Oxford.
King, R.B., Baillie, I.C., Abell, T.M.B., Dunsmore, J.R., Gray, D.Q., Pratt, J.H., Versey, H.R., Wright, A.C.S., Zisman, S.A., 1992. Land Resource Assessment of Northern Belize, Volume I and II. In: Natural Resources Institute Bulletin, 43. Overseas Development Natural Resources Institute Publication, Kent.
Maggetti, M., 1982. Phase analysis and its significance for technology and origin. In: Olin, J.S., Franklin, A.D. (Eds.), Archaeological Ceramics. Smithsonian Institutions Press, Washington, D.C, pp. 121–133.
Maniatis, Y., Tite, M.S., 1981. Technological examination of Neolithic-Bronze Age pottery from central and southeast Europe and from the near east. J. Arch. Sci. 8, 59–76.
Middleton, A., Freestone, I., 1991. Recent Developments in Ceramic Petrology. British Museum, London.
Morton, S.G., 2010. Investigations in Actun Lubul Ha. In: Andres, C.R., Wrobel, G.D. (Eds.), The Caves Branch Archaeological Survey Project: a Report of the 2010 Field Season, Belize Archaeological Research and Education Foundation Occasional Report No. 2. Mississippi, Oxford, pp. 41–49.
Papachristodoulou, C., Gravani, K., Oikonomou, A., Ioannides, K., 2010. On the provenance and manufacture of red-slipped fine ware from ancient Cassope (NW Greece): evidence by X-ray analytical methods. J. Arch. Sci. 37, 2146–2154.
Pendergast, D.M., 1979. Excavations at Altun Ha, Belize, 1964-1970, Volume I. Royal Ontario Museum, Toronto.
Pérez-Arantegui, J., Castillo, J.R., 2000. Characterisation of red-coloured slips (Almagra) on Islamic ceramics in Muslim Spain. Archaeometry 42 (1), 119–128.
Rands, R.L., 1973. The Classic Maya collapse: Usumacinta zone and the northwestern periphery. In: Culbert, T.P. (Ed.), The Classic Maya Collapse. University of New Mexico Press, Albuquerque, pp. 165–206.
Reents-Budet, D.J. (Ed.), 1998. Painting the Maya Universe: Royal Ceramics of the Classic Period. Duke University Press, Durham.
Reents-Budet, D., Bishop, R.L., 2015. Imitation or innovation? Molded-carved pottery and Terminal Classic times in the Petén lowlands. In: Paper Presented at the Andrea Stone Memorial Conference. North Arizona University, Flagstaff.
Sabloff, J.A., 1973. Continuity and disruption during Terminal Late Classic times at Seibal: ceramic and other evidence. In: Culbert, T.P. (Ed.), The Classic Maya Collapse. University of New Mexico Press, Albuquerque, pp. 107–132.
Sabloff, J.A., Willey, G.R., 1967. The collapse of Maya civilization in the southern lowlands: a consideration of history and process. Southwest. J. Anthropol 23 (4), 311–335.
Santley, R.S., Killion, T.W., Lycett, M.T., 1986. On the Maya collapse. J. Anthropol. Res. 42 (2), 123–159.
Shennan, S., 1997. Quantifying Archaeology. Edinburgh University Press, Edinburgh.
Shepard, A.O., 1964. Ceramics for the Archaeologist. Publication 609, Fifth ed. Carnegie Institution of Washington, Washington D.C.
Shipley III, W.E., Graham, E., 1987. Petrographic analysis and preliminary source identification of selected stone artefacts from the Maya site of Seibal and Uaxactun, Guatemala. J. Arch. Sci. 14, 367–383.
Smith, R.E., 1958. The place of Fine Orange pottery in Mesoamerican archaeology. Am. Ant. 24 (2), 151–160.
Stuart, D., 1993. Historical inscriptions and the Maya collapse. In: Sabloff, J.A., Henderson, J. (Eds.), Lowland Maya Civilization in the Eighth Century A.D. Dumbarton Oaks Research Library and Collection, Washington, D.C, pp. 321–354.
Sunahara, K.S., 2009. Ancient Maya Ceramic Economy in the Belize River Valley Region: Petrographic Analyses. Archaeopress, Oxford.
Ting, C., Graham, E., MartinÍŒn-Torres, M., 2014. Molding the 'collapse': technological analysis of the Terminal Classic molded-carved vases from Altun Ha, Belize. In: Martinón-Torres, M. (Ed.), Craft and science: international perspectives on archaeological ceramics. Bloomsbury Qatar Foundation, Doha, pp. 53–63.
Ting, C., 2015. Data from the production and exchange of moulded-carved vases and the 'Maya collapse'. J. Open Archaeol. Data 4, e4. http://dx.doi.org/10.5334/joad.ai.
Ting, C., Helmke, C., 2013. Technology, production, and distribution of Terminal Classic molded-carved vases in the Central Maya lowlands. Open J. Archaeom. 1 (1), 43–48.
Ting, K.C., 2013. Change, Continuity, and the Maya Collapse: Reconstructing the Ceramic Economy in the Eastern Maya Lowlands during the Classic to Postclassic Transition. Unpublished Ph.D. Dissertation. UCL Institute of Archaeology, London.
Tite, M.S., Freestone, I.C., Meeks, N.D., Bimson, M., 1982. The use of scanning electron microscopy in the technological examination of ancient ceramics. In: Olin, J.S., Franklin, A.D. (Eds.), Archaeological Ceramics. Smithsonian Institution Press, Washington D.C, pp. 109–120.
Tite, M.S., Maniatis, Y., 1975. Examination of ancient pottery using the scanning electron microscope. Nature 257, 122–123.
Villaseñor, I., Graham, E., 2010. The use of volcanic materials for the manufacture of Pozzolanic plasters in the Maya lowlands: a preliminary report. J. Arch. Sci. 37, 1339–1347.
Willey, G.R., 1986. The Postclassic of the Maya lowlands: a preliminary overview. In: Sabloff, J.A., Andrews, V. E.W. (Eds.), Late Lowland Maya Civilization: Classic to Postclassic. University of New Mexico, Albuquerque, pp. 17–52.
Whitbread, I.K., 1995. Appendix 3: the collection, processing and interpretation of petrographic data. In: Whitbread, I.K. (Ed.), Greek Transport Amphorae: a Petrological and Archaeological Study. British School at Athens, London, pp. 365–395.
Wolf, S., 2002. Estimation of the production parameters of very large Medieval bricks from St. Urban, Switzerland. Archaeometry 44 (1), 37–65.
Wright, A.C.S., Romney, D.H., Arbuckle, R.H., Vial, V.E., 1959. Land in British Honduras: Report of the British Honduras Land Use Survey Team. Colonial Research Publications No. 24. Her Majesty's Stationery Office, London.
Wrobel, G.D., Shelton, R., 2011. Preliminary salvage operations at Sapodilla Rockshelter. In: Andres, C.R., Wrobel, G.D. (Eds.), The Caves Branch Archaeological Survey Project: a Report of the 2010 Field Season. Belize Archaeological Research and Education Foundation, Oxford, pp. 18–40. Occasional Report No. 2.